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UTILITY OF A GHOST HORIZON AND CLIMB/DIVE LADDER LINE TAPERING ON A HEAD-UP DISPLAY

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The voluntary, fully informed consent of the subjects used in this research was obtained as required by AFR 169-3.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*
As part of a United States Air Force (USAF) effort to standardize head-up display (HUD) symbology, an unusual attitude recovery task was employed to investigate the utility of a cue, the ghost horizon, that indicates the direction of the actual horizon when the climb/dive ladder (CDL) horizon line is not within the HUD field of view. Six HUD-experienced and 6 non-HUD-experienced military pilot subjects were used to determine whether there was improvement, with the ghost horizon, in ability to recover from nose-down unusual attitudes in a flight simulator. The ghost horizon was evaluated with 3 different CDL line configurations (tapered, nontapered, reverse tapered). In terms of accuracy of the initial stick input, the ghost-horizon configurations resulted in significantly better performance (about 11% better) than did the non-ghost-horizon configurations. The ghost horizon had no effect on initial stick input reaction time or total recovery time. The CDL line taper configuration did not affect accuracy, initial stick input reaction time, or total recovery time. Subjective data indicated that the pilots did not have a strong preference for any of the configurations. These findings suggest that the ghost horizon is a useful aid to unusual attitude recovery performance, and may reduce spatial disorientation.

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INTRODUCTION

The head-up display (HUD) was initially developed to aid pilots in the delivery of weapons. Engineers and pilots quickly realized that the HUD is also useful for displaying information such as altitude, airspeed, pitch, and bank. One advantage of presenting this flight information on the HUD is that it reduces the amount of time a pilot must spend head down in the cockpit and minimizes the number of visual transitions between the external world and the head-down instruments.

Unfortunately, a few unexpected problems were noticed as pilots began to rely more frequently on the HUD for aircraft control and performance indications. Aircraft were over-rotating on takeoff, causing the tail to drag; some "difficult to understand" collisions with the ground occurred in which the HUD was suspected to have been a contributing factor. Although these operational problems were identified earlier (Newman, 1980), it was not until the Aircraft Attitude Awareness Workshop in 1985 that researchers and pilots identified and agreed on the need for specific improvements. Deficient symbol design and mechanization, lack of symbology standardization, field-of-view (FOV) limitations, inadequate fault detection and warning indications, and poor training were identified as weaknesses with current HUDs (McNaughton, 1985). As a consequence of this focus of attention on HUD deficiencies, as well as general officer interest in HUD symbology problems, the United States Air Force (USAF) Instrument Flight Center was given the task to develop a standardized HUD symbology set for use during instrument flight.

Standardization of the symbology set provided a foundation for resolving many of the operational problems associated with the HUD. A standard symbology set would simplify the design, mechanization, terminology, fault indication, and training issues. The ensuing attempt to address these issues resulted in controversy (Roscoe, 1987; Newman, 1987; Iavecchia, Iavecchia & Roscoe, 1988) and research (Previc, 1989; Ercoline & Gillingham 1990; Weinstein & Ercoline, 1991; Weinstein, Ercoline, Evans & Bitton, 1992). As a result of a time- and resource-consuming effort, the USAF has developed a preliminary or "draft" symbology set.

Figure 1 shows the proposed standard symbology set as of December 1991. Although research efforts have helped resolve a number of the standardization issues, several aspects of the symbology have yet to be determined (Bitton & Evans, 1991). These include: 1) the format for bearing information, 2) the utility of various global attitude references, 3) the utility of display augmentation techniques (e.g., quickening, compression, and caging), and 4) the optimal means of indicating instrument failures.

The research effort reported here examined two issues that remain unresolved in the development of a global attitude reference: the utility of a cue to indicate the direction of the horizon when the climb/dive ladder (CDL) horizon line is not within the HUD FOV, and the configuration of the bottom half of the climb/dive ladder.

As the CDL moves vertically, and the horizon line reaches a set distance (determined by the HUD FOV size) from the edge of the instantaneous FOV, it is replaced by a ghost horizon line. The ghost horizon line, as originally conceived, is a dashed horizon line with "tepees" pointing upward, i.e., toward the sky (Fig. 2). The ghost horizon line extends across the entire FOV of the HUD, as does the conventional, solid, CDL horizon line. Once the true horizon is again located

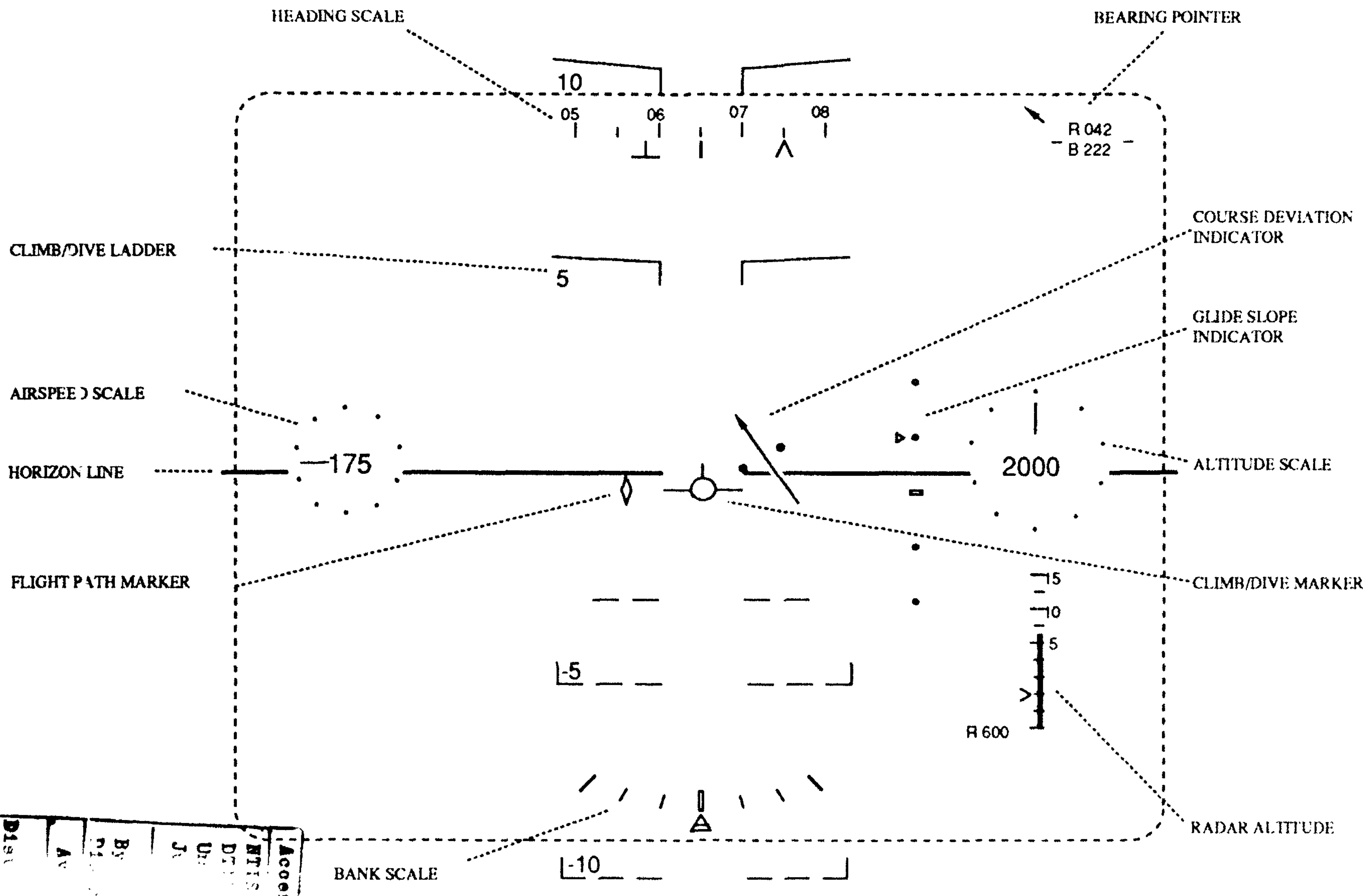

Figure 1. Proposed composite standard HUD symbology set.

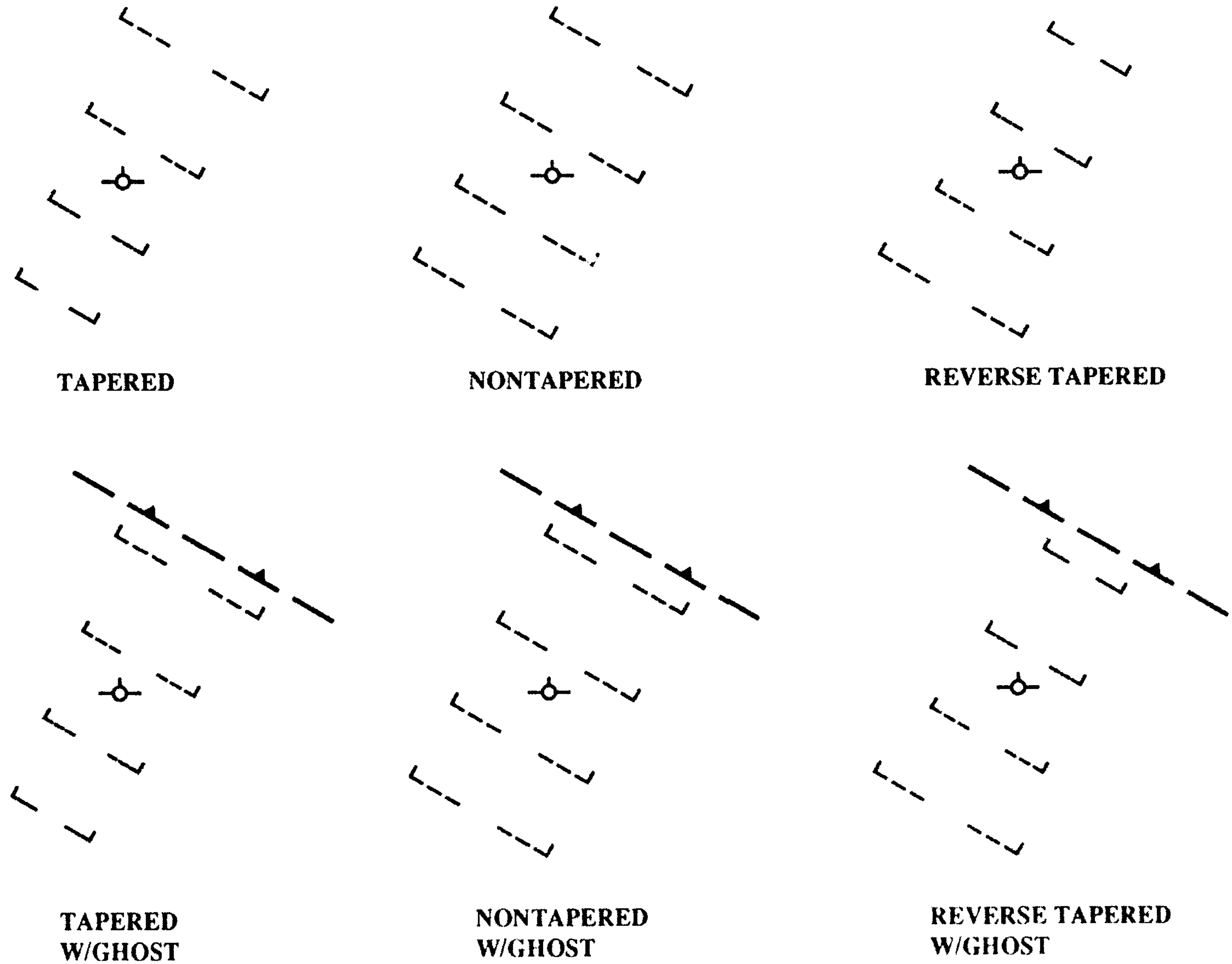

Figure 2. The 3 CDL line configurations evaluated in the experiment with and without the ghost horizon.

within the HUD FOV, the ghost horizon is replaced by the CDL horizon line (Bitton and Evans, 1991). In this study, the ghost horizon was evaluated to determine whether it can help pilots regain spatial orientation under conditions characterized by loss of attitude awareness (unusual attitude recovery situations).

The study also examined various line configurations for the bottom half of the CDL. The top half of the CDL contained solid, "articulated" lines. The lines pivoted at the inner corners and were angled at half the amount represented by that climb/dive line: e.g., the 40-degree line was articulated 20 degrees. A line was drawn at every 5 degrees of climb/dive angle (CDA). The CDL was drawn with linearly decreasing space between lines with increasing CDAs, so that the distance between the horizon line and the 5-degree line was 2.7 times the distance between the 85-degree line and the zenith or nadir symbol. Figure 2 illustrates the three types of lines that were evaluated for the bottom half of the CDL with and without a ghost horizon: tapered (became shorter with increasingly negative CDAs), nontapered (same length for all CDAs), and reverse tapered (became longer with increasingly negative CDAs). The evaluation involved recognition and recovery from unusual attitudes in a flight simulator.

METHOD

Subjects and Apparatus

Six HUD-experienced and six non-HUD-experienced military pilots volunteered to participate in the study. The average total flight time for all of the subjects was 2,870 h, and the HUD-experienced pilots had an average of 730 h of HUD flying time. The pilots had experience in a number of HUD-equipped aircraft, including the F-15, F-16, F-117, A-10, F-14, and F-18.

The experiment was conducted in the Visual Orientation Laboratory (VOL) in the Crew Technology Division, Crew Systems Directorate of the USAF Armstrong Laboratory at Brooks AFB, Texas. The VOL includes: (a) a Silicon Graphics IRIS 3130 computer workstation, (b) a Sony VPH-1030Q1 color video projector, (c) a subject booth containing a Draper Cine-15 viewing screen, and (d) a simulated F-16 aircraft seat with a side-arm force-stick controller on the right and a throttle on the left. Both the video projector and the viewing screen are adjustable in height, thus allowing the center of the projected image to be set at eye level for each subject while sitting in the simulated aircraft seat.

Procedure

At the beginning of each unusual attitude recovery trial, the pilots were seated in front of a blank screen, and initiated each trial by pulling a trigger on the control stick. The recovery task involved returning a HUD to a wings-level, upright, level-flight indication as quickly as possible. The subjects were asked to perform 20 different unusual attitude recoveries with each of the 6 HUD configurations, which resulted in a total of 120 trials per subject. All trials were run during one session that lasted approximately 90 min. Subjects were allowed to practice free-flying and unusual attitude recoveries with each HUD configuration immediately before completing the experimental trials for that configuration.

Only the nose-low unusual attitude recoveries were scored because the USAF does not specify one technique for recovery from nose-high unusual attitudes. The lack of consistency between the pilots in recovery techniques for the nose-high recoveries would have made it very difficult to determine accuracy of the responses and would have created large variations in reaction times. For nose-low recoveries, the correct procedure according to Air Force Manual 51-37,

Instrument Flying, is to achieve less than 90 degrees of bank and then apply back pressure as needed to return to a wings-level, upright attitude (Rastellini, 1986).

The dependent variables analyzed were accuracy of initial stick input (i.e., whether the subject initially rolled in the correct direction), the reaction time to the initial stick input, and the total recovery time. Analyses of variance (ANOVAs) were done on the accuracy, reaction-time, and recovery-time data. Subjects were also asked to complete a preference questionnaire at the completion of the session.

RESULTS AND DISCUSSION

There were no significant differences in performance or subjective evaluation due to prior HUD experience. Therefore, the data were collapsed across the two groups of pilots for analysis. The data analysis results for the CDL line configuration effects collapsed across ghost horizon condition are presented first, followed by the data analysis results for the ghost horizon effects collapsed across CDL line configuration.

The CDL line configuration (taper) did not affect unusual attitude recovery performance, nor did the pilots prefer any one CDL line configuration over any other. This was true with and without the ghost horizon. The mean accuracy (correctness) of the initial stick input as a function of the three CDL line configurations is shown in Figure 3. There was no statistically significant difference in accuracy due to the CDL line configuration (i.e., tapered 89%, nontapered 89%, reverse tapered 90%). Figure 4 illustrates the mean reaction time to the first significant stick input as a function of CDL line configuration. There was no statistically significant difference in initial reaction time due to the CDL line configuration (i.e., tapered .74 s, nontapered .77 s, reverse tapered .74 s). The mean total time to complete the recovery as a function of CDL configuraton is shown in Figure 5. The statistical analysis revealed no significant effect on total recovery time due to the CDL configuration.

The accuracy (correctness) of the initial stick input, with respect to presence or absence of the ghost horizon, is illustrated in Figure 6. An ANOVA conducted on the accuracy data to assess the differences in recovery performance with and without the ghost horizon revealed a significant effect due to the horizon type ($F(1,11) = 16.25$, $p < .01$). The ghost-horizon configurations resulted in significantly more accurate performance (95%) than did the non-ghost-horizon configurations (84%). The mean reaction time to the first significant stick input as a function of ghost-horizon condition is shown in Figure 7. The analysis on the initial stick input reaction-time data revealed no significant difference between configurations (i.e., ghost .73 s, no ghost .76 s). Figure 8 illustrates the mean total time to complete the unusual attitude recovery as a function of whether the ghost horizon was present or absent. The difference in total recovery time related to ghost-horizon condition was not statistically significant (i.e., ghost 11.35 s, no ghost 11.38 s).

The results of the preference survey revealed that 7 subjects had a preference for the ghost horizon, and 5 subjects preferred not to have it. Comments made by the pilots suggest that, although the ghost horizon is useful, the design of the horizon may not be optimal. Several subjects mentioned that they were confused by the "tepees" on the horizon line, because the "tepees" are sky pointers while the "ticks" on the climb/dive lines are horizon pointers. They suggested removing the "tepees," since the primary objective of the ghost horizon is to show the pilot the direction of the horizon. Several other subjects commented that the ghost horizon cluttered the display. If the "tepees" were removed, then the clutter on the display would be reduced. In addition, the "tepees" require a significant amount of computing power, and removing them would alleviate some of the computational load on the aircraft HUD. We feel confident that

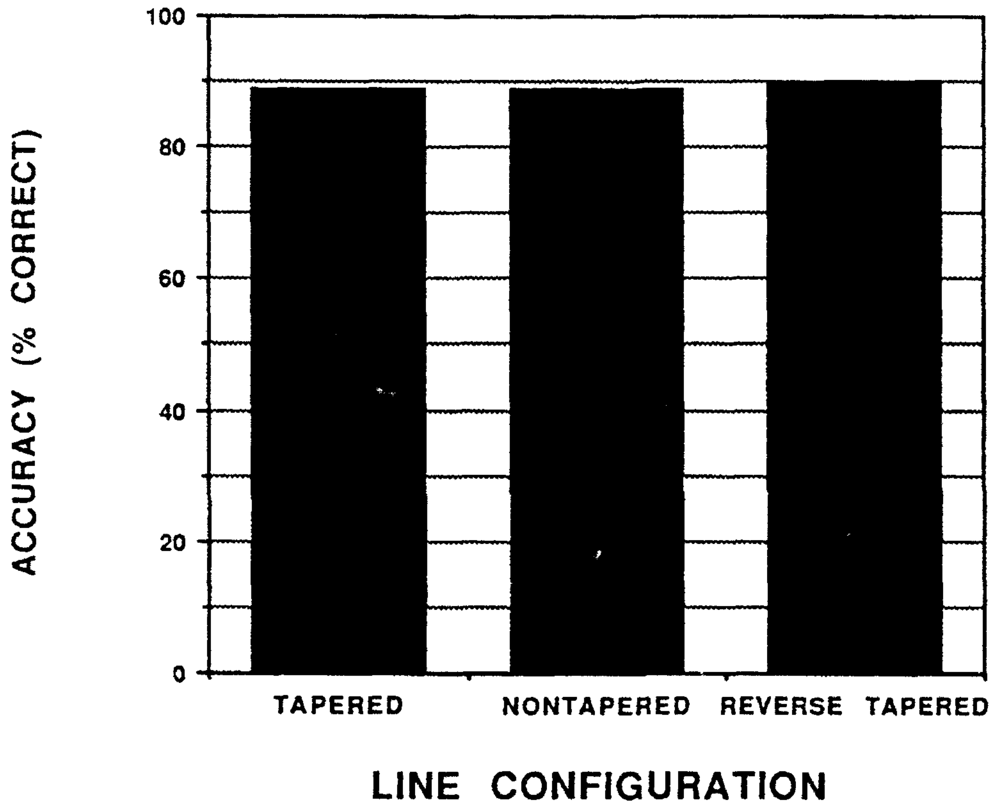

Figure 3. The mean accuracy (correctness) of the initial stick input as a function of the three CDL line configurations.

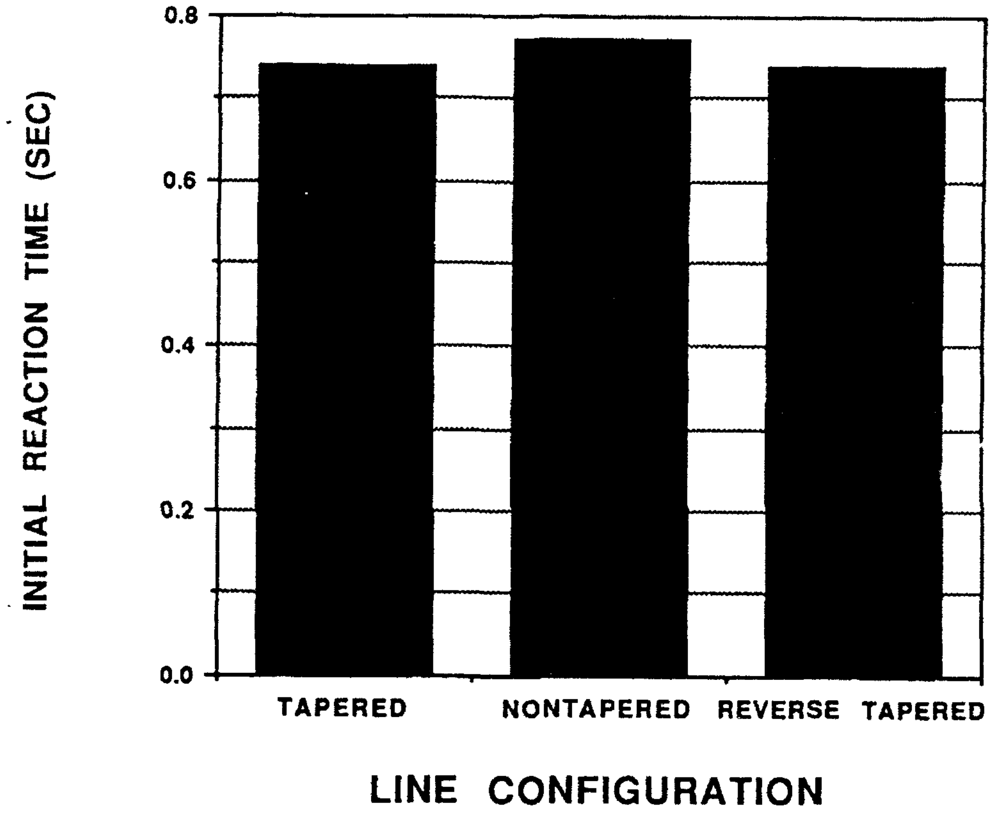

Figure 4. The mean reaction time to the first significant stick input as a function of CDL line configuration.

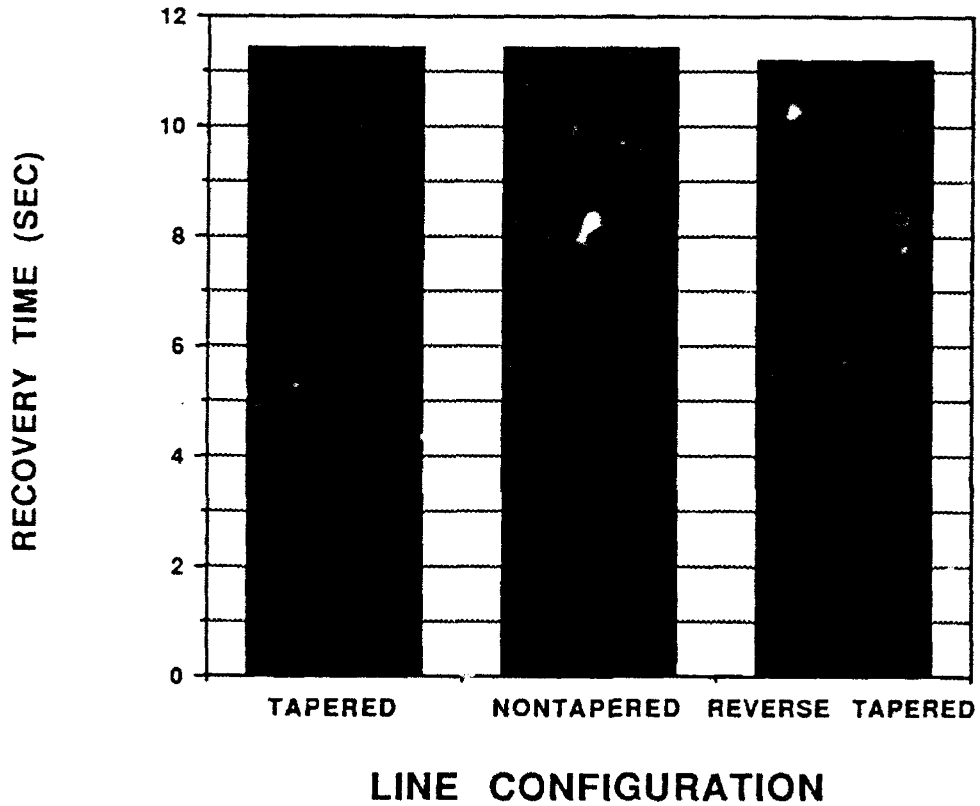

Figure 5. The mean total time to complete the recovery as a function of CDL line configuration.

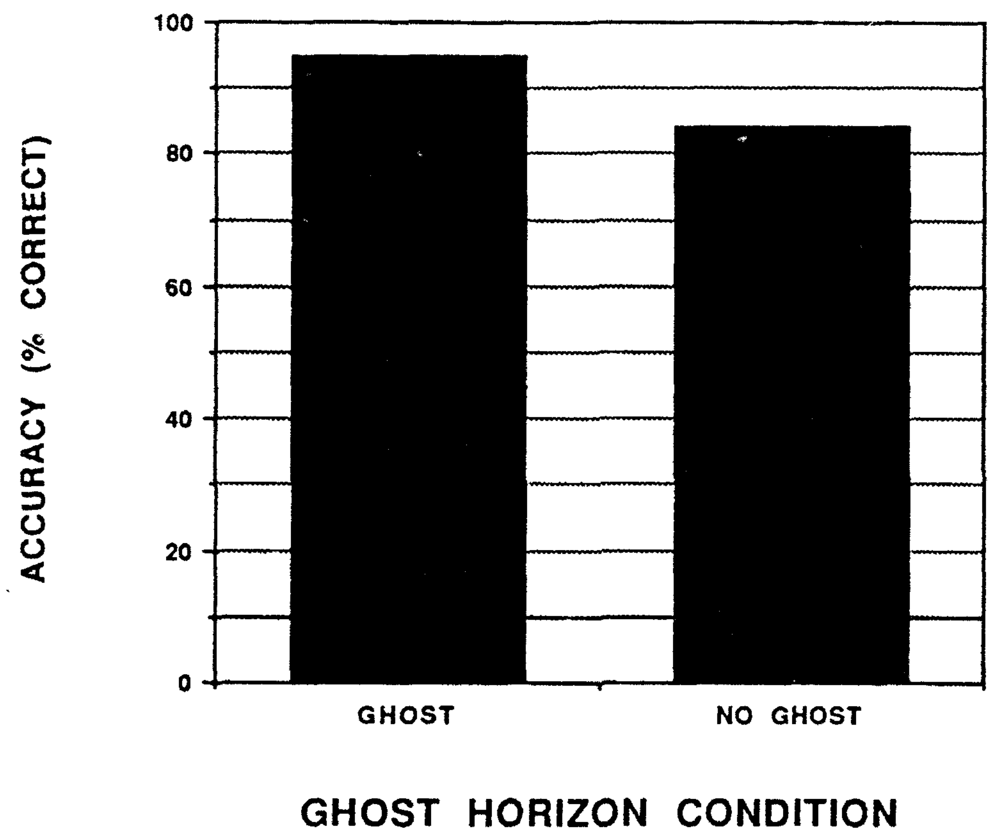

Figure 6. The accuracy (correctness) of the initial stick input, with respect to presence or absence of the ghost horizon.

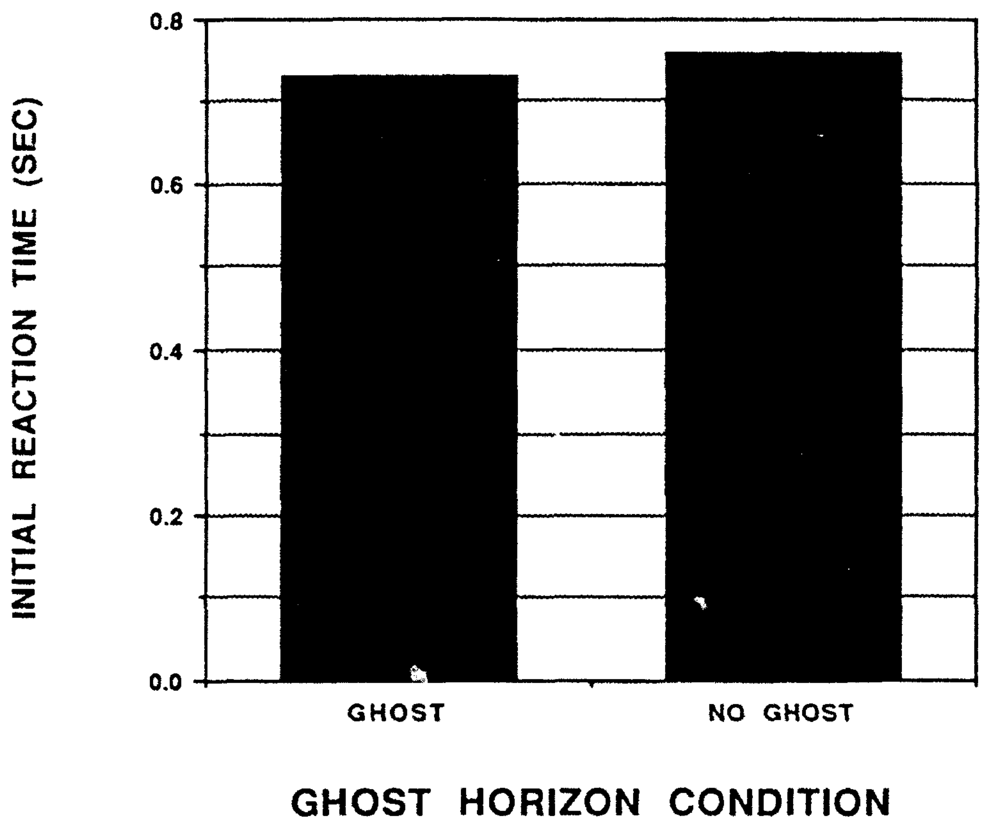

Figure 7. The mean reaction time to the first significant stick input as a function of ghost horizon condition.

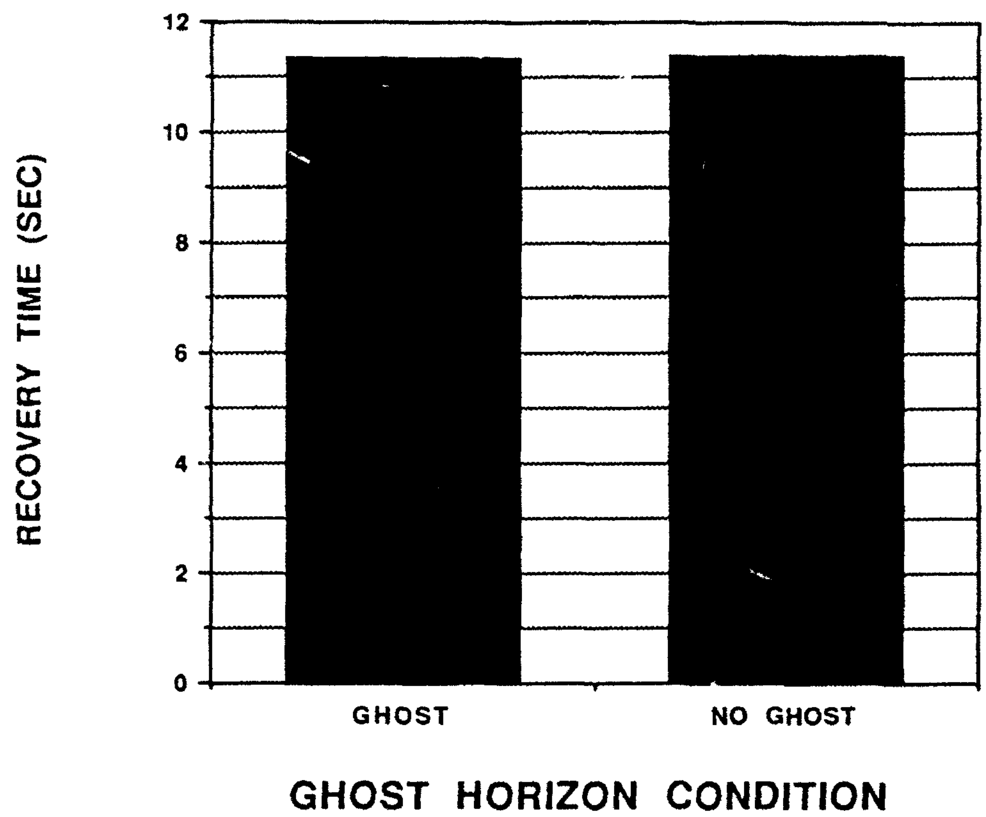

Figure 8. The mean total time to complete the unusual attitude recovery as a function of whether the ghost horizon was present or absent.

removing the "tepees" would not have diminished the performance benefits observed in this study because the subjective comments suggested that most pilots were unaware of the "tepees" or found them distracting.

CONCLUSIONS

Several conclusions can be drawn from the results. First, recovery from unusual attitudes can be helped by use of a ghost horizon, as evidenced by increased accuracy of initial response when the ghost horizon was presented. Second, the ghost horizon did not affect initial reaction time or total recovery time for unusual attitude recoveries. Third, the CDL line configurations (tapering, etc.) used in this study do not appear to affect the speed or accuracy with which a pilot can execute a nose-down unusual attitude recovery. As a result of these findings, the USAF Instrument Flight Center will support the inclusion of a modified (no "tepees") ghost horizon in the USAF standard HUD symbology set.

The USAF organization responsible for overseeing flight instrument development, the Joint Cockpit Office (JCO), in cooperation with the USAF Instrument Flight Center, Wright Laboratory, Armstrong Laboratory, Aeronautical Systems Division, and the Flight Test Center, has used the results of this and other studies to draft a USAF standard symbology set for use with the HUD as a primary flight reference. The proposed symbology set was evaluated in a simulator and underwent flight testing.

Since the original draft of this manuscript was submitted, the results of the inflight validation of the proposed draft standard were released and several changes were made to the symbology set. A decision by the JCO reversed the configurations of the top and bottom halves of the CDL. As a result, the new draft standard has articulated lines in the bottom half of the CDL and tapered lines in the top half of the CDL. In addition, new symbols were drawn to represent the climb/dive marker (CDM) and flight-path marker (FPM). Figure 9 illustrates the most recent draft standard, which was subjected to an inflight validation in the summer of 1992. The results of the second inflight validation were released in January 1993. The results of the inflight validation were favorable, and the symbology set depicted in Figure 9 will be included in a revision of Military Standard (MIL-STD) 1787, Aircraft Display Symbology.

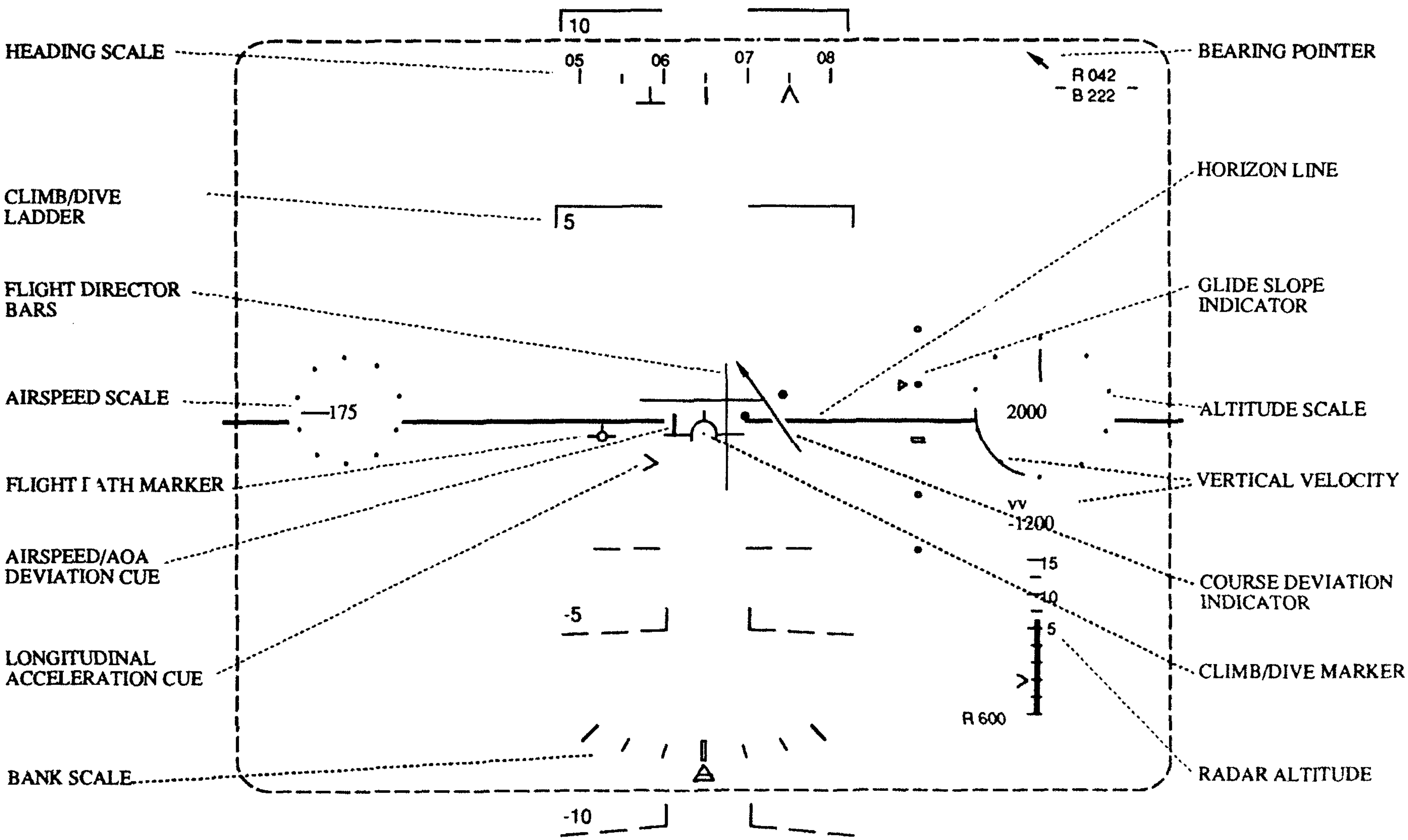

Figure 9: The proposed standard HUD symbology set (NOV 92).

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